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ES&H Section

RADIATION PHYSICS NOTE 128

Airborne Radioactivity in Accelerator Division

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Introduction

The purpose of this Note is to address airborne radioactivity concerns in Accelerator Division (AD) from all sources relative to the requirements of the Occupational Radiation Rule, 10CFR835. In Accelerator Division there are two potential sources of airborne radioactivity:

1. Airborne radioactivity resulting from cutting, burning, and machining operations on radioactive materials, and

2. Airborne radioactivity resulting from proton beam operation within Accelerator Division enclosures.

Airborne Radioactivity Resulting from Cutting Operations

Airborne radioactivity resulting from cutting operations was addressed in Radiation Physics Note 116. The conclusion of that paper was that the exposure rate of radioactive material had to exceed 525 mR/hr at one foot before airborne radioactivity concentrations could possibly exceed 10% of the DAC as a result of cutting, burning, and machining operations.

10 CFR 835.403 (a) (1) requires that "air sampling be performed in occupied areas where, under typical conditions, an individual is likely to receive an annual intake of 2% or more of the specified ALI values."

To address the requirement that air sampling be performed at 2% of the ALI, 525 mR/hr is divided by 5 to obtain a calculated dose rate at which 2% of the DAC may be approached. This calculation conservatively assumes that a worker would be occupationally exposed to 2 % of the DAC for 2000 hours per year, resulting in a potential intake of 2 % of the ALI. However, it is unlikely that a worker would be exposed to such occupational conditions. The result is that cutting, burning, and machining operations on materials with an approximate dose rate of 100 mR/hr at one foot,

which corresponds to "class 4" materials, could result in the worker being exposed to 2 % of the DAC. If the worker were occupationally exposed for 2000 work hours at 2 % of the DAC, then air sampling would be required. Therefore, based upon the calculations and assumptions of this paper and RP note 116, a guideline for evaluating the need to perform air sampling is given here:

> Prolonged exposure to cutting, burning, grinding, and/or machining operations involving Class 4 materials may produce airborne radioactivity concentrations which could lead to an intake by exposed workers of 2% of the ALI if the worker is occupationally exposed for 2000 work hours per year. Evaluations of cutting, burning, grinding, and/or machining operations for class 4 materials should include consideration for airborne radioactivity monitoring.

Currently, Accelerator Division evaluates all cutting and grinding operations on all radioactive materials.

Airborne Radioactivity Resulting from Beam Operation

Airborne radioactivity is produced when particle beams interact with beam line components or enclosure air; the resulting cascade of secondary particles which travel through beam enclosure air cause the air to become activated. The radio-isotopes which form are short-lived positron emitters and are sources of external exposure, primarily annihilation photons. A comparison of the relative values of DACs for these isotopes listed in Appendix A (internal) and Appendix C (immersion) of the Rule shows that external exposure from immersion is the limiting concern; internal radiation exposure due to these isotopes is negligible when compared to the corresponding imersion exposure. Significant levels of activity are only produced in areas of significant beam loss or where primary beam passes through air. Ambient levels of radioactivity due to activated beam line components far out-weigh that contributed by airborne radioactivity. Dose rate and radiation dose from airborne radioactivity is measurable with the portable survey instruments (LSMs) and personnel monitoring devices (TLDs and pocket dosimeters) respectively.

Airborne radioactivity area is defined in 10CFR835 as "any area where the measured concentration of airborne radioactivity , above natural background, exceeds or is likely to exceed 10 percent of the derived air concentration (DAC) values listed in Appendix A or C" of the rule. In later sections of this Note, it will become clear that portions of AD beam enclosures do exceed 10% of DAC values during operation of accelerators and beam transport lines.

Beam enclosures are defined as exclusion areas during periods of operation and personnel access is prohibited due to exposed and energized electrical bus, high radiation levels due to the proton beam and the increased Oxygen Deficiency Hazard. 10CFR835.601, General Requirements for Posting

and Labeling, requires the "working area" to be posted for radiological purposes. While 10CFR835 provides no explicit definition for "working areas", an implicit definition requires at least that a person or persons be able to be present in order for exposure to occur. Since personnel are not able to be present while beam is operable, we conclude that no posting is required while beam is operable.

When beam is disabled and personnel access becomes possible, the production of airborne radioactivity ceases. For some finite period of time at the beginning of beam enclosure access however, it is possible under certain conditions at certain beam enclosure locations for airborne radioactivity to persist above 10% of the DAC. One may infer from the commentary section of the Federal Register preceding the rule that time-weighted averaging (TWA) over a shift may be used to determine the applicability of the Rule where instantaneous rates are changing rapidly.

The goal of this note is to show whether an 8 hour TWA airborne radioactivity levels exceed 10% of the DAC under the limiting safety envelope conditions.

At the time of this writing, only some AD beam enclosures may exceed 10% of the DAC as defined in the rule. There are no areas outside of the beam enclosures where airborne radioactivity approaches or is likely to exceed 10 % of the DAC.

Airborne Radioactivity Data Collection

AD radiological control personnel installed stack monitors (see Table 1) for a number of beam enclosure locations where significant beam loss was known to occur. The stack monitors were connected to the MUX system to permit continuous data collection throughout the installation period. The AD controls system monitors the MUX system and a data-logger (Lumberjack) was used to log airborne radioactivity data. The controls system also records beam intensity information by a program called Beam Budget Monitor (BBM). Since airborne radioactivity levels vary directly with beam intensity, it was important to correct detector response for beam intensity permitted by the Safety Envelope.

Air was drawn from beam loss points to stack monitors (empty, one-gallon paint cans with a thin window 4.445 cm diameter GM tube) at a flowrate of 4 lpm through lengths of Tygon tubing. The air was pumped from the paint can and returned through another tygon tube to the enclosure. The GM tube is connected to a Ludlum 177-4 rate-meter, modified to produce one TTL MUX output pulse for each 100 GM detector counts. Lumberjack corrects for this conversion so that retrieved data may be used directly.

Table 1. Sampling and Instrumentation Locations, Tube Lengths

Sample Location	Stack monitor location	Tygon tubing length
Transfer Hall	Transfer Hall cul-de-sac near staging area	200'
F-17 Main Ring	F-1 Service Bldg	150'
Booster MPØ1	East Booster Gallery	150'
Booster MPØ2	West Booster Fan Room	100'
Linac 400 MeV	Linac MUX Relay Rack	50'
Linac NTF	Linac Gallery Lower Level	50'
Pre-Vault	AP0 Building	50'

Assumptions for Data Analysis

Techniques to make direct qualitative and/or quantitative measurement of gaseous, short-lived, positron-emitting isotopes are not available. Previous work in this area and some assumptions are necessary to proceed.

1. We assume that the type and relative abundance of gaseous radio-isotopes produced are similar over the energy spectrum from 400 MeV to 1 TeV. The relative abundances derived for the stack in RP Note 106 were adjusted in this work to correct for decay which occurs between the stack and the vault. The result is that we have the relative abundances at the source, i.e., the pbar target vault. We assume the relative abundances at the pbar source are similar to those at other loss points discussed in this paper.

2. The very short-lived isotopes like O-15 and N-16 were not considered in RP Note 106 because these isotopes would have decayed away before being collected in the grab sample. For purposes of this note, isotopes such as O-15 and N-16 may be present in the sample and they would contribute to detector response. No accounting for their presence is taken in the calculations which follow. The effect on this work is likely to lead to an over-estimation of the airborne radioactivity levels after beam is turned off because the shorter lived isotopes would decay away very rapidly thereby decreasing potential exposure.

3. The gas counted in the stack monitor is assumed to be representative of that present in other beam enclosure. No correction is made for decay in the sample line. This effect could lead to an under-estimation of the DAC in the enclosure but should be more than offset by the very conservative assumption (#2) above.

4. The amount of airborne radioactivity produced for a given beam loss scenario is directly proportional to beam intensity.

5. Fluid dynamics are not well understood for air in tunnel enclosures and consequently, no credit is taken for dilution.

Source Term Calibration Factor

In RP Note 106, a calibration factor was developed for the specific activity of gases leaving the pbar production area stack . For purposes of this note, a calibration factor is needed for the specific activity of gases produced at the point of generation. Since there was a 20 minute delay between the point and generation and exhaust of the gases at the stack in RP Note 106, application of a decay correction is necessary.

Values for the first five lines of Table 2 are copied directly from RP Note 106. The percentage of the total activity from each isotope ($\%N_{true}$) in Table 2 reflects the isotopic composition at the AP0 stack. Application of the 20 minute decay correction yields the specific activity of each isotope at the vault (N_{true} (Bq) Decay Corrected) , the point of generation. Counting efficiencies for stack monitors used in this paper were provided by the ES&H Section(1). Finally, Table 2 provides a calibration factor (mCi/ml-cpm), to convert data (in cpm) from stack monitors to a specific activity by isotope at the point of radioisotope production.

Table 2. Decay Corrected Composition of AP0 Stack Monitor Grab Sample and Calculated Isotope Activity at Point of Generation per Stack Monitor cpm

Isotope	N-13	C-11	Cl-38	Cl-39	Ar-41
N_O (counts per sec)	27	33.8	1.1	1.1	1.1
$\%N_O$	42.1	52.7	1.7	1.7	1.7
e GM in RPN 106	13.2%	10.7%	21.3%	18.3%	13.3%
N_{true} (Bq)	205	316	5.2	6.0	8.3
$\%N_{true}$	37.9	58.5	1.0	1.1	1.5
Half Life	9.97min	20.39min	37.24min	56.60min	109.6min
N_{true} (Bq) Decay Corrected	823	624	7.6	7.7	9.4
$\%N_{true}$ Decay Corrected	55.9	42.5	0.5	0.5	0.6
e GM this note	14.6%	11.9%	22.9%	20.0%	14.8%
N_O (counts per sec) Decay corrected	120.	74.3	1.74	1.5	1.4
pCi - Decay corrected	2.22E4	1.69E4	205	203	256
GM cpm	7200	4458	104	90	84
GM % Total cpm	60.3	37.35	0.87	0.75	0.70
pCi per gross GM cpm	1.86	1.42	1.72E-2	1.7E-2	2.14E-2
Calibration Factor mCi/ml-cpm	5.12E-10	3.91E-10	4.73E-12	4.68E-12	5.89E-12

Consideration of Radioactive Decay in the Sample Lines

Air is drawn through tygon tubing to a stack monitor. The stack monitor samples air at a flow rate of 4 liters per minute (LPM), so that with shorter lived nuclides it is necessary to consider the radioactive decay of these nuclides during the transit of sample air through the tubing. The length of tygon tubing at other enclosures reaches up to about 200' , in which case the time of decay is longer before the sample air reaches the monitor.

Tygon tubing is a half inch in diameter, which is a radius of about 0.02' . The volume of air inside 50' length of tubing is calculated:

$$(\pi r^2 l)\ [2.8 \times 10^{-2}\ m^3/ft^3] = \pi(0.02)^2(50')[2.8 \times 10^{-2}\ m^3/ft^3] = 1.76 \times 10^{-3}\ m^3$$

The time of transit for a unit volume of air in the tubing:

$$(1.76 \times 10^{-3}\ m^3)\ (10^3 L/m^3)/\ [(4\ LPM)] = 0.44 \text{ minutes}$$

A similar calculation for 200' of tubing yields a transit time of 1.76 minutes.

Since the times of transit of the sample in the sample tubes are short compared to the shortest half life (10 minutes for N-13), no corrections were made for decay.

Adjustment of Stack Monitor Data for Safety Envelope Beam Intensities

Data from each of the seven stack monitor was retrieved and evaluated for a period in which steady state accelerator operation was achieved. Beam intensity data for the same period was considered so that the stack monitor data could be adjusted up to the Safety Envelope values for the respective accelerators. The result is an estimate of the worst case count rate for each stack monitor which might be achievable assuming that the fractional beam loss does not change with beam intensity and assuming operation at the current allowable Safety Envelope intensities.

Table 4. Raw and Adjusted Stack Monitor Data by Location

Monitor MUX Quad/ Address	Location	Average CPM	Average Beam Intensity (p/h)	Allowed Beam Intensity (p/h)	% of Allowed Beam Intensity	Estimated Average cpm at Allowable Intensity
2-022	Transfer Hall	164	4.10E15	7.2E15	56.94	288
2-041	NTF (linac)	0				0*
2-043	MP02 (Booster)	243	5.30E15	9E15	58.89	413
2-046	400 MeV (linac)	274	1.25E16	3.4E17	3.68	274**
2-072	Prevault	7030	4.10E15	5.4E15	75.93	9259
2-130	MP01 (Booster)	2120	5.30E15	9E15	58.89	3600
2-245	F17 (Main Ring)	658	4.10E15	7.2E15	56.94	1156

* For NTF, no activity different from background was observed.

* * For linac, no correction of the average cpm to the estimated average cpm at the allowed beam intensity because the result is improbable. The booster accelerator is unable to accept the Linac Safety Envelope limit of beam intensity.

Determination of Airborne Radioactivity Concentrations for Various Accelerator Division Beam Enclosures

The data from Table 4 is used as input for a series of spreadsheets which are included as attachments #1 through #7. The worst case airborne radioactivity levels for current Safety Envelope limitations are determined on these spreadsheets. In four cases, the calculated airborne radioactivity does not exceed 10% of the DAC. In three cases, the calculated airborne radioactivity does exceed 10% of the DAC. In these cases, the spreadsheet is used to calculate the decay time required for the airborne radioactivity concentrations to be reduced to 10% of the DAC.

To understand the magnitude of the effect of the airborne radioactivity, a section of the spreadsheet shows the resulting committed effective dose equivalent (CEDE) which would result if a person could be exposed to the airborne radioactivity immediately after beam is disabled and until this source has decayed away. A second value is given if a nominal 20 minute delay is imposed. A third value is given to indicate the exposure one could receive if delay times are imposed for the three cases in which the threshold for posting is exceeded. This section is only provided where airborne radioactivity levels may ever exceed 10% of the DAC.

Regulatory Interpretation and Application of the Rule

Airborne radioactivity levels quickly diminish when particle beams are turned off. From a review of the DOE comments which appear in the Federal Register published along with the final Rule, it is clear that the use of time-weighted averaging is a possible approach to determine whether airborne radioactivity posting is required. The committed effective dose equivalent which results from exposure to 1 DAC-hour is 2.5 mrem. A worker exposed for an eight hour shift at a concentration of 1 DAC would receive an exposure of 8 DAC-hrs corresponding to a dose equivalent of 20 mrem. In order for a worker to be exposed to greater than 10% of the DAC over an 8 hour shift, it follows that one must be able to receive an exposure of 0.8 DAC-hrs per shift corresponding to a dose equivalent of about 2 mrem per shift due to airborne radioactivity.

A review of attachments #1 through #7 reveals only one location (Pre-vault) in which a 2 mrem exposure is conceivable. In order to receive 2 mrem, one must be able to enter the beam enclosure immediately after the beam is turned off. Since airborne concentrations are directly related to beam intensity delivered to the target, AD must also be able to deliver beam to the target at the maximum permitted rate. It is not operationally feasible to enter the beam enclosure until about 10 minutes after turning off the beam. In addition, AD is incapable of delivering protons to the target at rates much above 75% of the safety envelope limit. This will probably be the case until the Main Injector becomes operational. Thus, accesses which lead to such exposures are highly unlikely. Further, it is inconceivable that multiple accesses of this type could occur in a single specific day given the difficult of restarting the accelerator and operating it in a way which would lead to the "saturation" of these levels of airborne radioactivity.

Conclusion

Of the seven locations monitored, three produce instantaneous airborne radioactivity levels which exceed 10% of the DAC at limiting Safety Envelope beam intensities. The airborne radioactivity present consists solely of short-lived, positron emitters which do not pose an internal dosimetry concern. The resulting exposure to a person from airborne radioactivity is insignificant (less than 0.4 DAC-hrs per shift or 1 mrem per shutdown) compared with dose which accrues from radioactive beam line components at high beam loss points. This source of external radiation

exposure can be readily monitored with portable instrumentation and personal dosimetry currently in use. The production of this source of radiation exposure ends when the beam is turned off. Existing operational delays (e.g., locking off power at the Master Substation, checking out keys, transit time to enclosure) introduces decay time which reduces this already insignificant exposure potential. The eight hour, time-weighted average fraction of the DAC does not exceed 10% at any currently operational AD beam enclosures. Therefore, it is concluded that specific posting for airborne radioactivity is not required for AD spaces at this time.

A Rule of Thumb

It is useful to understand the stack monitor response which corresponds to a DAC of beam induced airborne radioactivity. Utilizing the attached spreadsheets, it has been determined that a count rate of approximately 4000 cpm corresponds to 1 DAC for the isotopes considered in this note.

References

1. Private conversation, Kamran Vaziri, Radiation Physicist, Fermilab ES&H Section

2. Kamran Vaziri, "APØ Stack Monitor Calibration", Radiation Physics Note 106, Fermilab ES&H Section

3. Federal Register, Vol. 58, No. 238, 10 CFR 835, Occupational Radiation Protection, Final Rule

MUX Quad/Address: 2-245 Enclosure: **F17 Main Ring**

Count Rate= (input stack monitor cpm) | INPUT CR **1156**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	6.07E-07	4.00E-06	1.52E-01
C-11	20	4.60E-07	4.00E-06	1.15E-01
Cl-38	37	5.58E-09	3.00E-06	1.86E-03
Cl-39	57	5.69E-09	3.00E-06	1.90E-03
Ar-41	110	6.95E-09	3.00E-06	2.32E-03

DAC RATIO SUM 2.73E-01

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 19.92

0.15	0.04
0.12	0.06
0.00	0.00
0.00	0.00
0.00	0.00
	0.10

Minutes until DAC ratio is below 0.10 19.92

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.091	N-13	0.023	N-13	0.023
C-11	0.138	C-11	0.069	C-11	0.069
Cl-38	0.004	Cl-38	0.003	Cl-38	0.003
Cl-39	0.006	Cl-39	0.005	Cl-39	0.005
Ar-41	0.015	Ar-41	0.014	Ar-41	0.014
Total CEDE for access which begins immediately after beam off	0.255 mrem	Total CEDE for access which begins 20 minutes after beam off	0.113 mrem	Total CEDE for access which begins 19.92 minutes after beam off	0.114 mrem

MUX Quad/Address: 2-046 Enclosure: **400MeV Linac**

Count Rate= (input stack monitor cpm) | INPUT CR: **274**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	1.44E-07	4.00E-06	3.60E-02
C-11	20	1.09E-07	4.00E-06	2.73E-02
Cl-38	37	1.32E-09	3.00E-06	4.41E-04
Cl-39	57	1.35E-09	3.00E-06	4.49E-04
Ar-41	110	1.65E-09	3.00E-06	5.49E-04

DAC RATIO SUM 6.47E-02

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 0.00

0.04	0.04
0.03	0.03
0.00	0.00
0.00	0.00
0.00	0.00
	0.06

Minutes until DAC ratio is below 0.10: 0.00

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.022	N-13	0.005	N-13	0.022
C-11	0.033	C-11	0.016	C-11	0.033
Cl-38	0.001	Cl-38	0.001	Cl-38	0.001
Cl-39	0.002	Cl-39	0.001	Cl-39	0.002
Ar-41	0.004	Ar-41	0.003	Ar-41	0.004
Total CEDE for access which begins immediately after beam off	0.061 mrem	Total CEDE for access which begins 20 minutes after beam off	0.027 mrem	Total CEDE for access which begins 0 minutes after beam off	0.061 mrem

MUX Quad/Address: 2-130 Enclosure: **MP01 Booster**

Count Rate= (input stack monitor cpm) INPUT CR **3600**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	1.89E-06	4.00E-06	4.73E-01
C-11	20	1.43E-06	4.00E-06	3.58E-01
Cl-38	37	1.74E-08	3.00E-06	5.80E-03
Cl-39	57	1.77E-08	3.00E-06	5.90E-03
Ar-41	110	2.16E-08	3.00E-06	7.21E-03

DAC RATIO SUM 8.50E-01

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 46.75

0.47	0.02
0.36	0.07
0.01	0.00
0.01	0.00
0.01	0.01
	0.10

Minutes until DAC ratio is below 0.10 46.75

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.284	N-13	0.071	N-13	0.011
C-11	0.431	C-11	0.215	C-11	0.085
Cl-38	0.013	Cl-38	0.009	Cl-38	0.005
Cl-39	0.020	Cl-39	0.016	Cl-39	0.011
Ar-41	0.048	Ar-41	0.042	Ar-41	0.036
Total CEDE for access which begins immediately after beam off	0.795 mrem	Total CEDE for access which begins 20 minutes after beam off	0.353 mrem	Total CEDE for access which begins 46.75 minutes after beam off	0.149 mrem

MUX Quad/Address: 2-043 Enclosure: **MP02 Booster**

Count Rate= (input stack monitor cpm) | INPUT CR **413**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	2.17E-07	4.00E-06	5.42E-02
C-11	20	1.64E-07	4.00E-06	4.11E-02
Cl-38	37	1.99E-09	3.00E-06	6.65E-04
Cl-39	57	2.03E-09	3.00E-06	6.77E-04
Ar-41	110	2.48E-09	3.00E-06	8.27E-04

DAC RATIO SUM 9.75E-02

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 0

0.05	0.05
0.04	0.04
0.00	0.00
0.00	0.00
0.00	0.00
	0.10

Minutes until DAC ratio is below 0.10 0.00

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.033	N-13	0.008	N-13	0.033
C-11	0.049	C-11	0.025	C-11	0.049
Cl-38	0.001	Cl-38	0.001	Cl-38	0.001
Cl-39	0.002	Cl-39	0.002	Cl-39	0.002
Ar-41	0.005	Ar-41	0.005	Ar-41	0.005
Total CEDE for access which begins immediately after beam off	0.091 mrem	Total CEDE for access which begins 20 minutes after beam off	0.041 mrem	Total CEDE for access which begins 0 minutes after beam off	0.091 mrem

MUX Quad/Address: 2-041 Enclosure: **NTF Linac**

Count Rate= (input stack monitor cpm) | INPUT CR: **0**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	0.00E+00	4.00E-06	0.00E+00
C-11	20	0.00E+00	4.00E-06	0.00E+00
Cl-38	37	0.00E+00	3.00E-06	0.00E+00
Cl-39	57	0.00E+00	3.00E-06	0.00E+00
Ar-41	110	0.00E+00	3.00E-06	0.00E+00

DAC RATIO SUM 0.00E+00

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t=		
0	0.00	0.00
	0.00	0.00
	0.00	0.00
	0.00	0.00
	0.00	0.00
		0.00

Minutes until DAC ratio is below 0.10: 0.00

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.000	N-13	0.000	N-13	0.000
C-11	0.000	C-11	0.000	C-11	0.000
Cl-38	0.000	Cl-38	0.000	Cl-38	0.000
Cl-39	0.000	Cl-39	0.000	Cl-39	0.000
Ar-41	0.000	Ar-41	0.000	Ar-41	0.000
Total CEDE for access which begins immediately after beam	0.000 mrem	Total CEDE for access which begins 20 minutes after beam off	0.000 mrem	Total CEDE for access which begins 0 minutes after beam off	0.000 mrem

MUX Quad/Address: 2-072 Enclosure: **Prevault**

Count Rate= (input stack monitor cpm) | INPUT CR **9259**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	4.86E-06	4.00E-06	1.22E+00
C-11	20	3.69E-06	4.00E-06	9.21E-01
Cl-38	37	4.47E-08	3.00E-06	1.49E-02
Cl-39	57	4.56E-08	3.00E-06	1.52E-02
Ar-41	110	5.56E-08	3.00E-06	1.85E-02

DAC RATIO SUM 2.19E+00

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 73.82

1.22	0.01
0.92	0.07
0.01	0.00
0.02	0.01
0.02	0.01
	0.10

Minutes until DAC ratio is below 0.10 73.82

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.731	N-13	0.183	N-13	0.004
C-11	1.108	C-11	0.554	C-11	0.086
Cl-38	0.033	Cl-38	0.023	Cl-38	0.008
Cl-39	0.052	Cl-39	0.041	Cl-39	0.021
Ar-41	0.123	Ar-41	0.108	Ar-41	0.077
Total CEDE for access which begins immediately after beam off	2.046 mrem	Total CEDE for access which begins 20 minutes after beam off	0.908 mrem	Total CEDE for access which begins 73.82 minutes after beam off	0.197 mrem

MUX Quad/Address: 2-022 Enclosure: **Transfer Hall**

Count Rate= (input stack monitor cpm) | INPUT CR **288**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	1.51E-07	4.00E-06	3.78E-02
C-11	20	1.15E-07	4.00E-06	2.87E-02
Cl-38	37	1.39E-09	3.00E-06	4.64E-04
Cl-39	57	1.42E-09	3.00E-06	4.72E-04
Ar-41	110	1.73E-09	3.00E-06	5.77E-04

DAC RATIO SUM 6.80E-02

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 0

0.04	0.04
0.03	0.03
0.00	0.00
0.00	0.00
0.00	0.00
	0.07

Minutes until DAC ratio is below 0.10 0.00

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.023	N-13	0.006	N-13	0.023
C-11	0.034	C-11	0.017	C-11	0.034
Cl-38	0.001	Cl-38	0.001	Cl-38	0.001
Cl-39	0.002	Cl-39	0.001	Cl-39	0.002
Ar-41	0.004	Ar-41	0.003	Ar-41	0.004
Total CEDE for access which begins immediately after beam off	0.064 mrem	Total CEDE for access which begins 20 minutes after beam off	0.028 mrem	Total CEDE for access which begins 0 minutes after beam off	0.064 mrem

MUX Quad/Address: 2-3005 Enclosure: **SWYD G2**

Count Rate= (input stack monitor cpm) | INPUT CR **800**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	4.20E-07	4.00E-06	1.05E-01
C-11	20	3.18E-07	4.00E-06	7.96E-02
Cl-38	37	3.86E-09	3.00E-06	1.29E-03
Cl-39	57	3.94E-09	3.00E-06	1.31E-03
Ar-41	110	4.81E-09	3.00E-06	1.60E-03

DAC RATIO SUM 1.89E-01

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 0

0.04	0.04
0.03	0.03
0.00	0.00
0.00	0.00
0.00	0.00
	0.07

Minutes until DAC ratio is below 0.10 0.00

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.063	N-13	0.016	N-13	0.063
C-11	0.096	C-11	0.048	C-11	0.096
Cl-38	0.003	Cl-38	0.002	Cl-38	0.003
Cl-39	0.004	Cl-39	0.004	Cl-39	0.004
Ar-41	0.011	Ar-41	0.009	Ar-41	0.011
Total CEDE for access which begins immediately after beam off	0.177 mrem	Total CEDE for access which begins 20 minutes after beam off	0.078 mrem	Total CEDE for access which begins 0 minutes after beam off	0.177 mrem

MUX Quad/Address: 2-3005 Enclosure: **SWYD PSEP**

Count Rate= (input stack monitor cpm) | INPUT CR **800**

Isotope	1/2 life	Enclosure Concentration µCi/ml	DAC'S	DAC RATIO
N-13	10	4.20E-07	4.00E-06	1.05E-01
C-11	20	3.18E-07	4.00E-06	7.96E-02
Cl-38	37	3.86E-09	3.00E-06	1.29E-03
Cl-39	57	3.94E-09	3.00E-06	1.31E-03
Ar-41	110	4.81E-09	3.00E-06	1.60E-03

DAC RATIO SUM 1.89E-01

If DAC Ratio sum is greater than or equal to 0.10 then posting required, or procedurally prohibit access for a determined time period.

t= 0

0.04	0.04
0.03	0.03
0.00	0.00
0.00	0.00
0.00	0.00
	0.07

Minutes until DAC ratio is below 0.10 0.00

0 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	20 minutes delay	Committed Effective Dose Equivalent (mrem) by Isotope	Minutes Delay Until concentration is <10% DAC	Committed Effective Dose Equivalent (mrem) by Isotope
N-13	0.063	N-13	0.016	N-13	0.063
C-11	0.096	C-11	0.048	C-11	0.096
Cl-38	0.003	Cl-38	0.002	Cl-38	0.003
Cl-39	0.004	Cl-39	0.004	Cl-39	0.004
Ar-41	0.011	Ar-41	0.009	Ar-41	0.011
Total CEDE for access which begins immediately after beam off	0.177 mrem	Total CEDE for access which begins 20 minutes after beam off	0.078 mrem	Total CEDE for access which begins 0 minutes after beam off	0.177 mrem